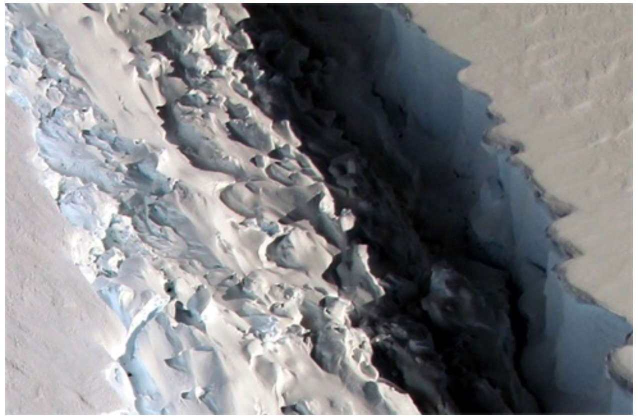
SCIENCE






Algorithms Working Group

Kerry Cawse-Nicholson, Philip A. Townsend
Jet Propulsion Laboratory, California Institute of Technology
University of Wisconsin Madison

June 12, 2019




Goals and current working group

- A formal charter to support mission concept development by assessing the status of existing algorithms, identifying gaps and opportunities, and assisting in traceability studies.
- An express obligation to offer community input and transparency.
- 120+ working group members
- Biweekly telecons (20 – 60 participants)
- 50+ contributors to Team Drive
- Subgroups in aquatics, geology, snow, vegetation, and thermal
- **200+ products have been suggested by the community!**




Tasks

- Consider available algorithms, their uncertainty and computing requirements,
- Consider whether any given algorithm should be applied globally or to a subset (pre-classification, different algorithms).
- Prepare prototype workflow for sample products
- Use and acquire precursor airborne and space-based imagery to demonstrate prototype level 3 and level 4 products
- Prepare a final report recommending algorithms for each product along with a list of required ATBDs.

Algorithms working group roles

SBG Science & Applications Objectives

Priority	Panel	Description
Most Important Objectives		
E1c	Ecosystems	Quantify the physiological dynamics of terrestrial and aquatic primary producers.
E2a		Quantify the fluxes of CO_2 and CH_4 globally at spatial scales of 100 to 500 km and monthly temporal resolution with uncertainty <25% between land ecosystems and atmosphere and between ocean ecosystems and atmosphere.
E3a		Quantify the flows of energy, carbon, water, nutrients, etc. sustaining the life cycle of terrestrial and marine ecosystems and partitioning into functional types.
H1c	Hydrology	Quantify rates of snow accumulation, snowmelt, ice melt, and sublimation from snow and ice worldwide at scales driven by topographic variability.
S1a	Solid Earth	Measure the pre-, syn-, and post-eruption surface deformation and products of Earth's entire active land volcano inventory at a time scale of days to weeks.
Very Important Objectives		
E1a	Ecosystems	Quantify the distribution of the functional traits, functional types, and composition of vegetation and marine biomass, spatially and over time.
H2a	Hydrology	Quantify how changes in land use, water use, and water storage affect evapotranspiration rates, and how these in turn affect local and regional precipitation systems, groundwater recharge, temperature extremes, and carbon cycling.
H4a		Monitor and understand hazard response in rugged terrain and land margins to heavy rainfall, temperature and evaporation extremes, and strong winds at multiple temporal and spatial scales. This socioeconomic priority depends on success of addressing H-1b and H-1c, H-2a, and H-2c.
S1c	Solid Earth	Forecast and monitor landslides, especially those near population centers.
S2b		Assess surface deformation (<10 mm), extent of surface change (<100 m spatial resolution) and atmospheric contamination, and the composition and temperature of volcanic products following a volcanic eruption (hourly to daily temporal sampling).
C3a	Climate	Quantify CO_2 fluxes at spatial scales of 100-500 km and monthly temporal resolution with uncertainty <25% to enable regional-scale process attribution explaining year-to-year variability by net uptake of carbon by terrestrial ecosystems (i.e., determine how much carbon uptake results from processes such as CO_2 and nitrogen fertilization, forest regrowth, and changing ecosystem demography.)
W3a	Weather	Determine how spatial variability in surface characteristics modifies regional cycles of energy, water and momentum (stress) to an accuracy of 10 W/m2 in the enthalpy flux, and 0.1 N/m2 in stress, and observe total precipitation to an average accuracy of 15% over oceans and/or 25% over land and ice surfaces averaged over a 100 × 100 km region and 2- to 3-day time period.

Sample products

Priority	Panel	Description	
H1	Hydrology	Snow fraction Snow albedo Snow surface temperature Snow – light absorbing particles	Snow algae concentration Snow grain size Evapotranspiration
H2		Reflectance Water-leaving reflectance HDRF-corrected reflectance BRDF-corrected reflectance Emissivity Surface temperature	Evapotranspiration Evaporative stress index Water use efficiency Plant photosynthetic capacity Albedo
H4		See H1	
W3	Water	Water surface temperature	

Most Important Objectives	
H1c	Quantify rates of snow accumulation, snowmelt, ice melt, and sublimation from snow and ice worldwide at scales driven by topographic variability.
Very Important Objectives	
H2a	Quantify how changes in land use, water use, and water storage affect evapotranspiration rates, and how these in turn affect local and regional precipitation systems, groundwater recharge, temperature extremes, and carbon cycling.
H4a	Monitor and understand hazard response in rugged terrain and land margins to heavy rainfall, temperature and evaporation extremes, and strong winds at multiple temporal and spatial scales. This socioeconomic priority depends on success of addressing H-1b and H-1c, H-2a, and H-2c.
W3a	Determine how spatial variability in surface characteristics modifies regional cycles of energy, water and momentum (stress) to an accuracy of 10 W/m2 in the enthalpy flux, and 0.1 N/m2 in stress, and observe total precipitation to an average accuracy of 15% over oceans and/or 25% over land and ice surfaces averaged over a 100 × 100 km region and 2- to 3-day time period.

Priority	Panel	Description	
E1	Ecosystems	Biochemical traits of water biomass Water quality (including phytoplankton and HAB) Benthic environment Water surface environment (floating biotic material) Water hazards (flotsam) Water environment (temperature, IOP) Wetlands	Evapotranspiration Plant functional traits Soil maps and carbon content Plant functional type Veg species and distribution fAPAR Cover fractions
E2		Biochemical traits of water biomass Water quality (including phytoplankton and HAB) Water surface environment (floating biotic material)	Water environment (temperature, IOP) Wetlands Evapotranspiration
E3		Biochemical traits of water biomass Water quality (including phytoplankton and HAB) Benthic environment Water surface environment (floating biotic material) Water hazards (flotsam) Water environment (temperature, IOP) Wetlands	Evapotranspiration Evaporative Stress Index Water use efficiency Plant functional traits Plant functional type Veg species and distribution Cover fractions

Most Important Objectives	
E1c	Quantify the physiological dynamics of terrestrial and aquatic primary producers.
E2a	Quantify the fluxes of CO_2 and CH_4 globally at spatial scales of 100 to 500 km and monthly temporal resolution with uncertainty <25% between land ecosystems and atmosphere and between ocean ecosystems and atmosphere.
E3a	Quantify the flows of energy, carbon, water, nutrients, etc. sustaining the life cycle of terrestrial and marine ecosystems and partitioning into functional types.

Sample products

Priority	Panel	Description	
S1	Surface geology	Surface temperature Volcanic product suite Surface deformation	Seismic product suite Mineralogy Soils
S2		Volcanic product suite Composition changes Surface thermal properties	Seismic products Event recovery
S4		Surface composition changes Lithology Seismic products	Volcanic products Landscape changes Event recovery

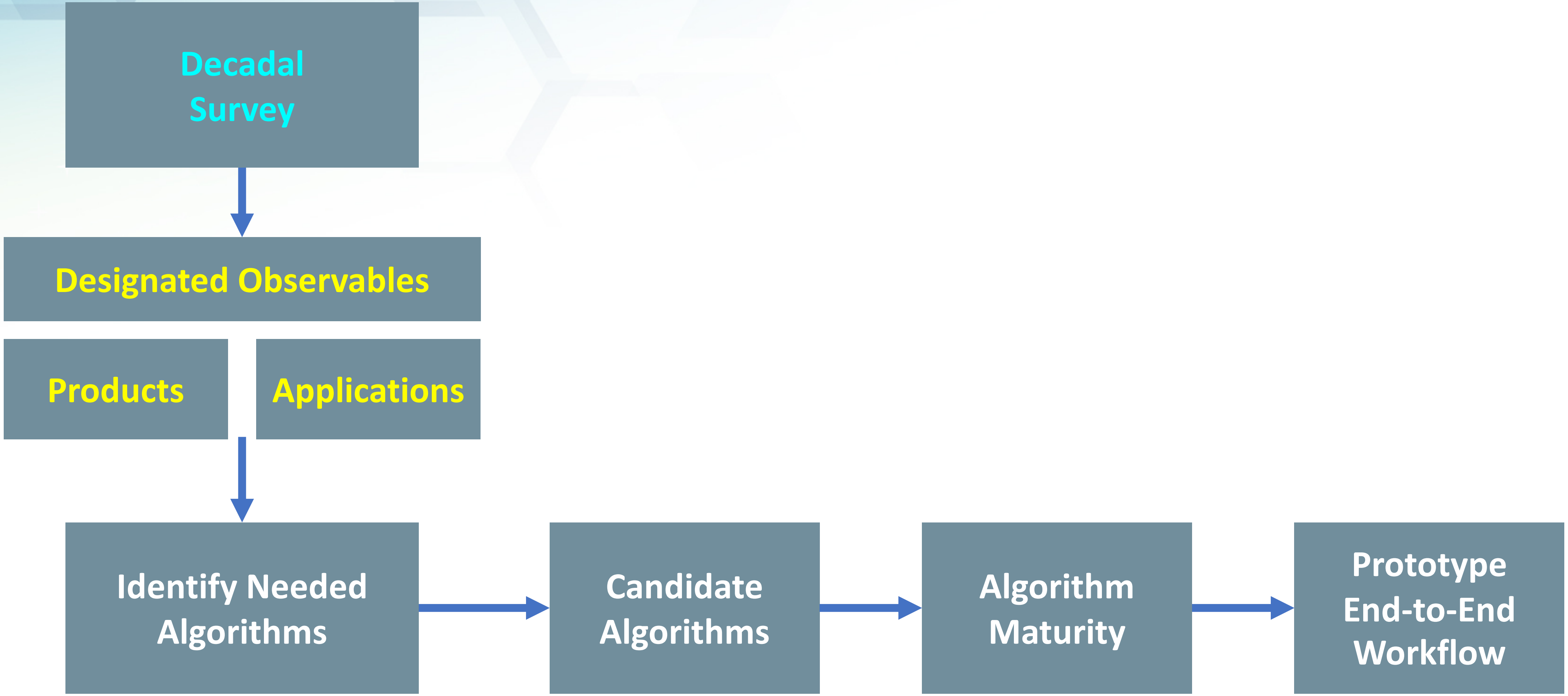
Most Important Objectives	
S1a	Measure the pre-, syn-, and post-eruption surface deformation and products of Earth's entire active land volcano inventory at a time scale of days to weeks.

Very Important Objectives	
S1c	Forecast and monitor landslides, especially those near population centers.
S2b	Assess surface deformation (<10 mm), extent of surface change (<100 m spatial resolution) and atmospheric contamination, and the composition and temperature of volcanic products following a volcanic eruption (hourly to daily temporal sampling).

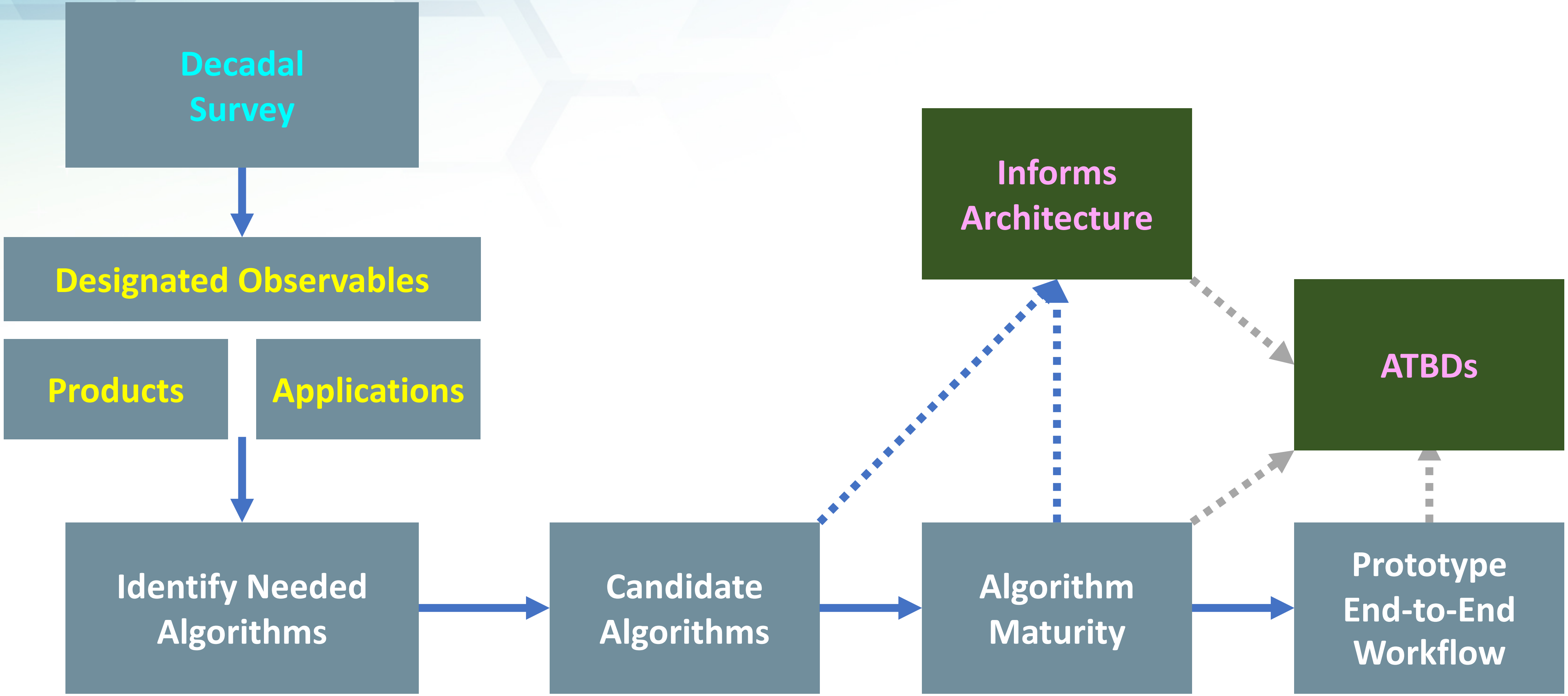
Next steps

- Finalize product list and required algorithms following community feedback
- End-to-end workflows for sample products
- Phase 1 final report due in September 2019
- Phase 2: evaluation of architectures using the value framework, which will include product assessment
- Join us for dinner at Asia Nine, 915 E St NW!

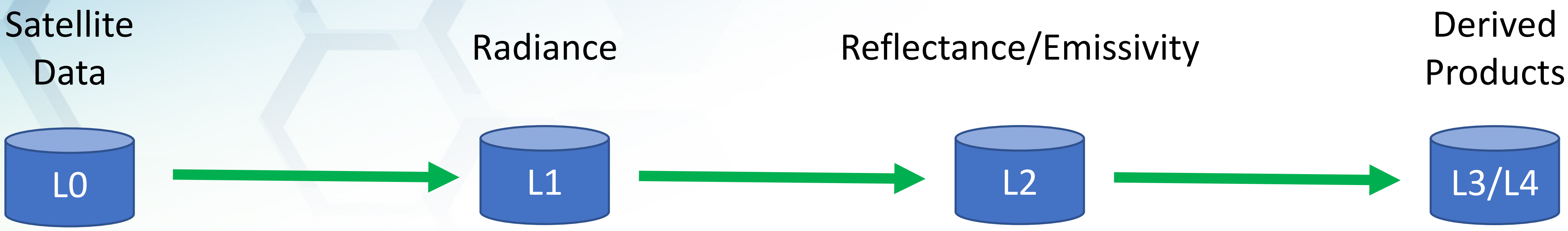
Algorithms Team



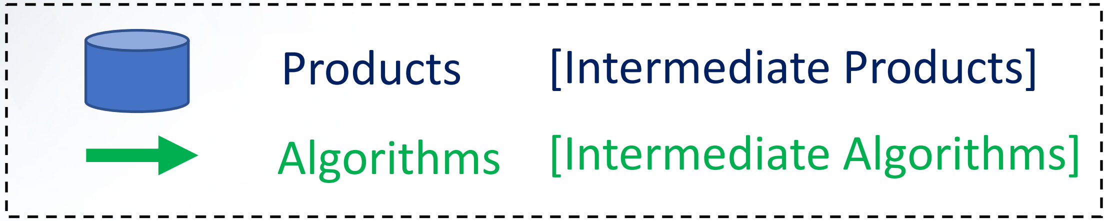
Algorithms Team

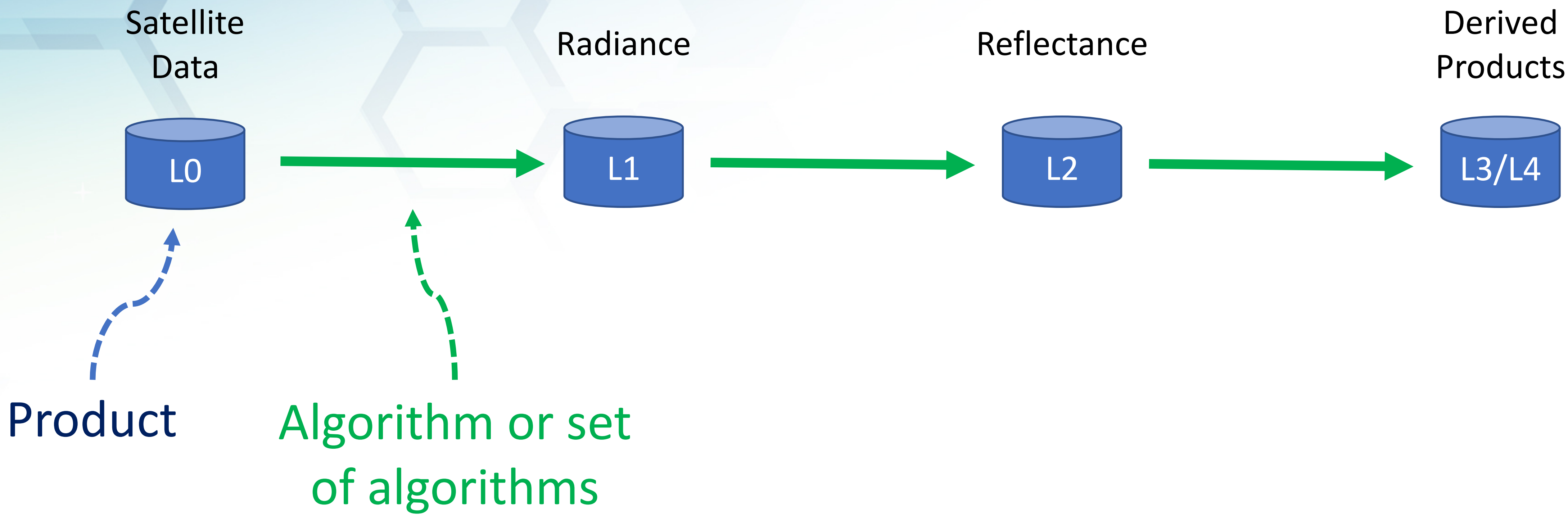


Framework for algorithm workflow

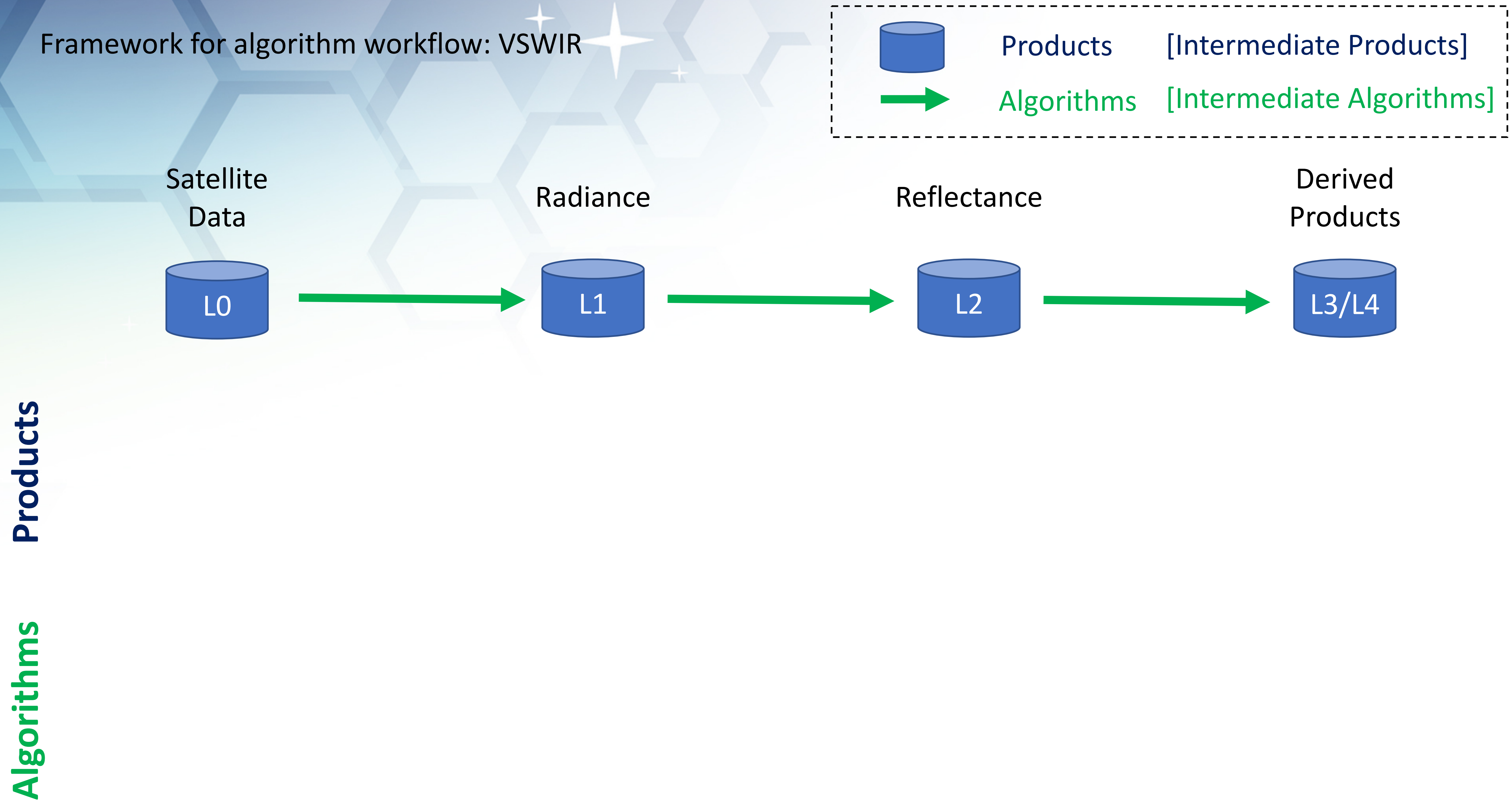


Framework for algorithm workflow: VSWIR

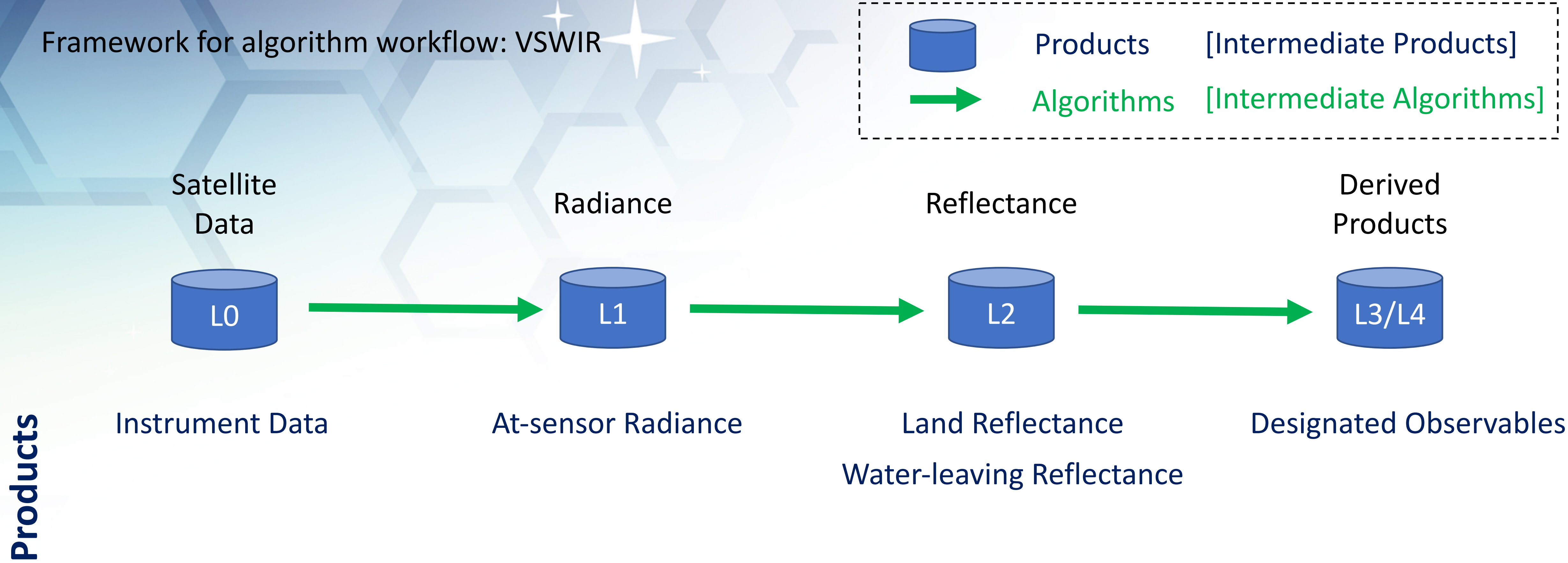




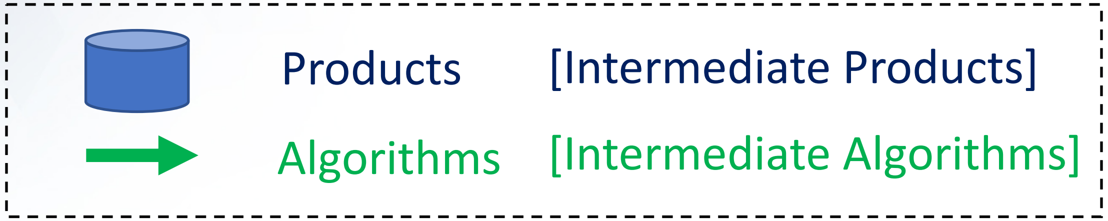
Framework for algorithm workflow: VSWIR

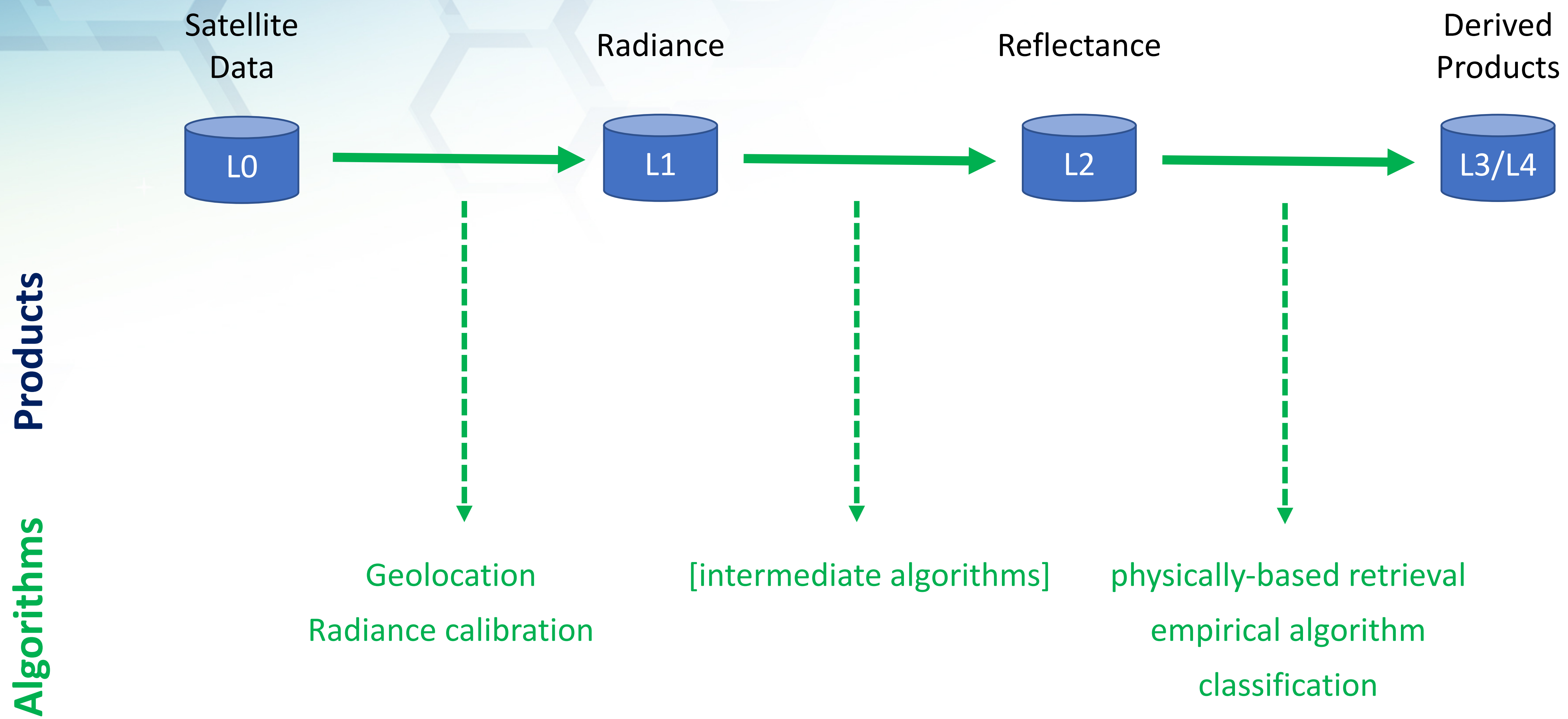


Framework for algorithm workflow: VSWIR

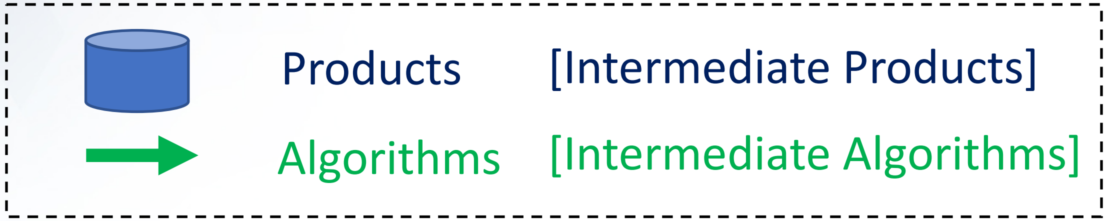


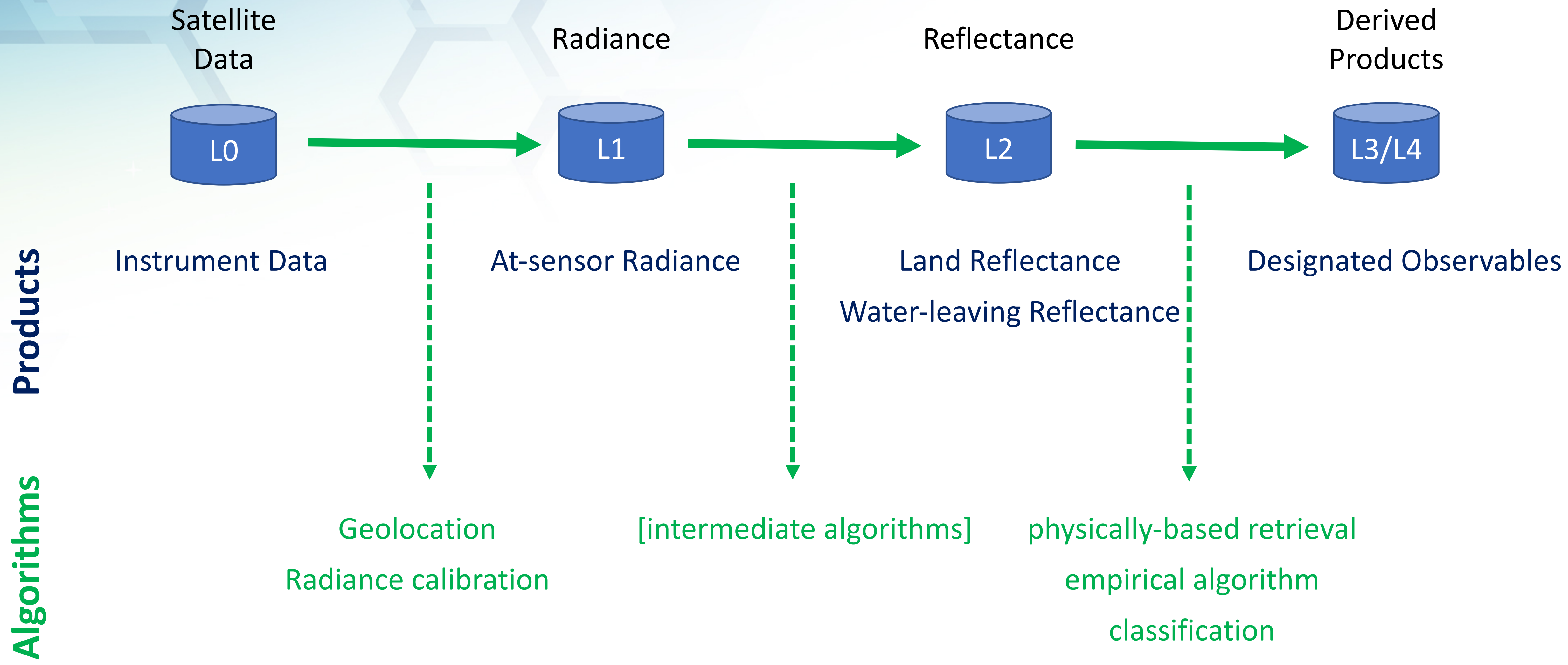
Framework for algorithm workflow: VSWIR



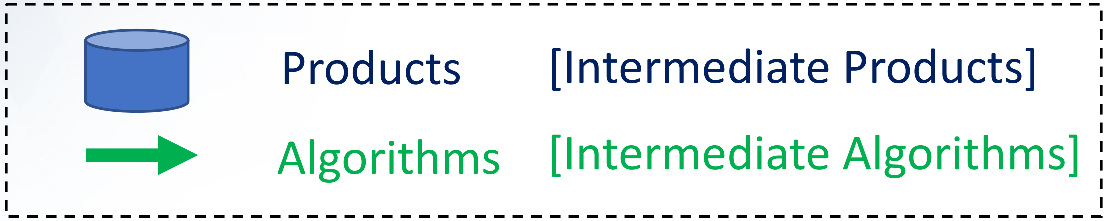


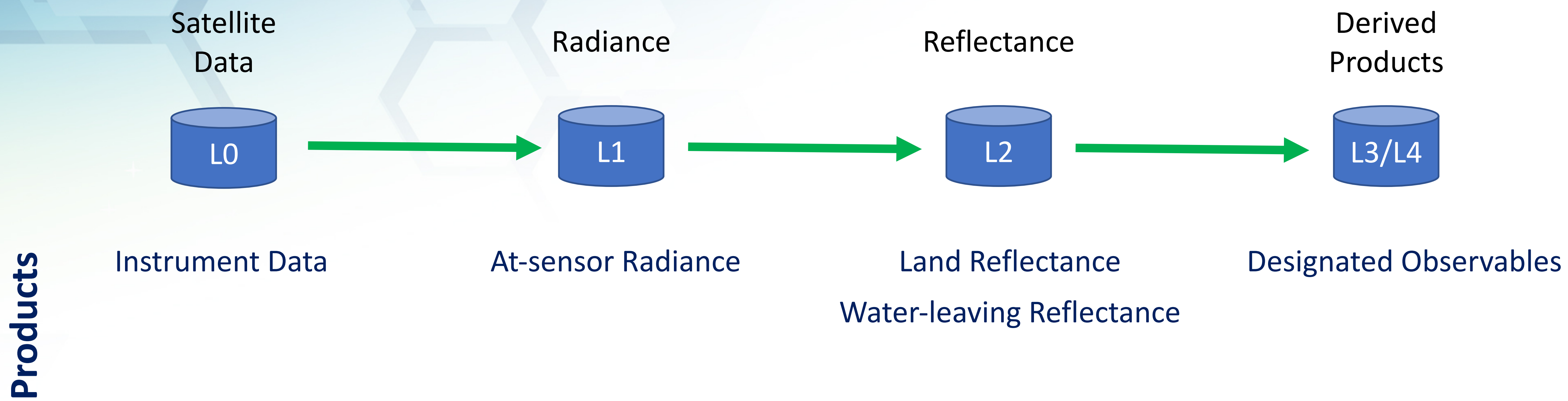
Framework for algorithm workflow: VSWIR



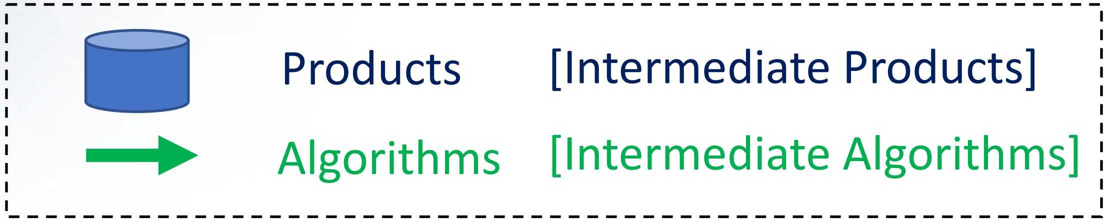


Framework for algorithm workflow: VSWIR





Framework for algorithm workflow: VSWIR



Satellite Data | Radiance | Reflectance | Derived Products

Products

Algorithms

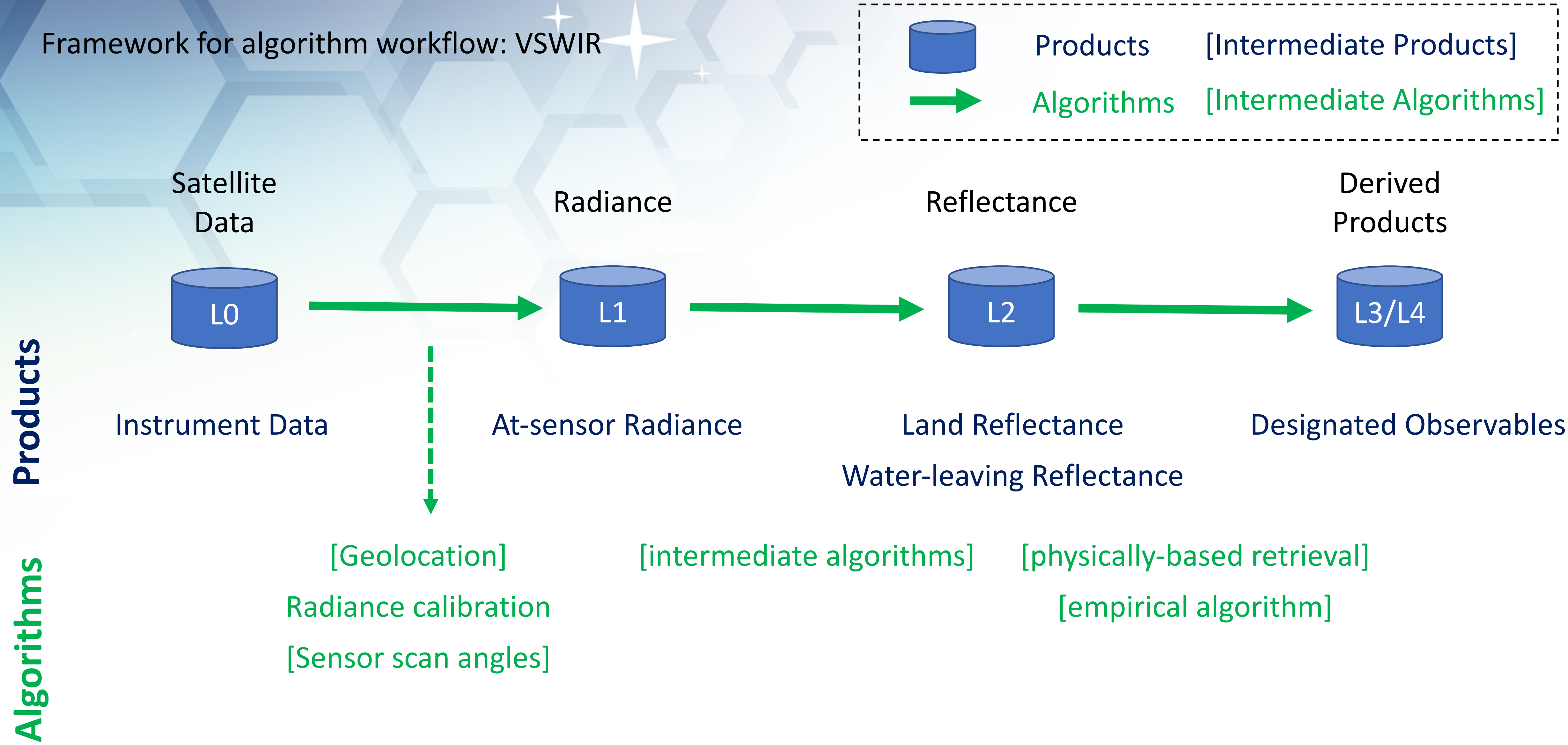
Instrument Data
[cloud filter]
[pointing/prioritization]
[compress/decompress]
[dark frame]
[sensor temperature]
[vicarious calibration]
[sensor model]

At-sensor Radiance

Land Reflectance
Water-leaving Reflectance

Designated Observables

Framework for algorithm workflow: VSWIR

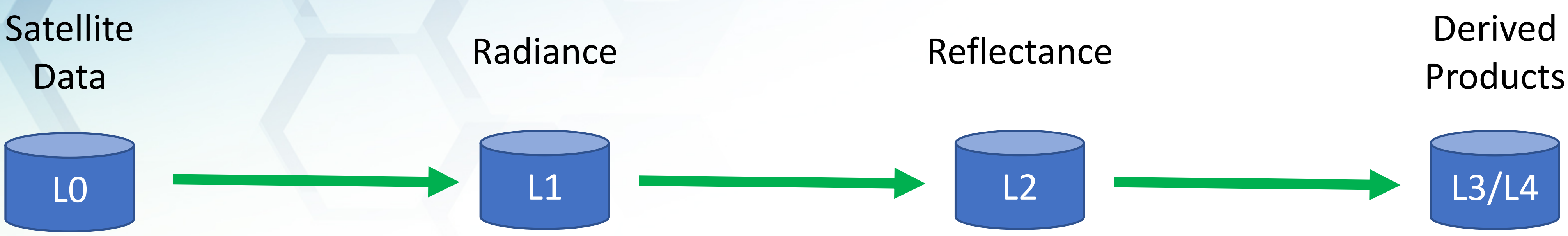


Framework for algorithm workflow: VSWIR

General workflow needed for all products

Products [Intermediate Products]

Algorithms [Intermediate Algorithms]



Products

Instrument Data

[cloud filter]

[pointing/prioritization]

[compress/decompress]

At-sensor Radiance

Land Reflectance

Water-leaving Reflectance

Designated Observables

Algorithms

Geolocation

Radiance calibration

[intermediate algorithms]

[physically-based retrieval]

[empirical algorithm]

Framework for algorithm workflow: VSWIR

Products [Intermediate Products]

Algorithms [Intermediate Algorithms]

Products

Satellite Data	Radiance	Reflectance	Derived Products
Instrument Data	At-sensor Radiance	Land Reflectance	Designated Observables
[cloud filter]		Water-leaving Reflectance	
[pointing/prioritization]		[Cloud, Shadow, Haze]	
[compress/decompress]		[Land, Water mask]	

Algorithms

L0 → L1	L1 → L2	L2 → L3/L4
Geolocation	Cloud/shadow	[physically-based retrieval]
Radiance calibration	Haze	[empirical algorithm]
	Land/Water	
	Atmospheric Correction	

Framework for algorithm workflow: VSWIR TERRESTRIAL VEGETATION EXAMPLES

Products [Intermediate Products]

Algorithms [Intermediate Algorithms]

Satellite Data | Radiance | Reflectance | Derived Products

Products

Instrument Data

[sensor algorithms]

[decision algorithms]

[data store/transmit alg.]]

At-sensor Radiance

Land Reflectance

Water-leaving Reflectance

BRDF Corrected Reflectance

BRDF/Topo Corr. Reflectance

Designated Observables

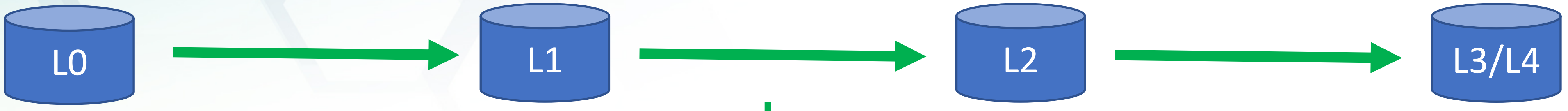
Algorithms

Framework for algorithm workflow: VSWIR TERRESTRIAL VEGETATION EXAMPLES

Products [Intermediate Products]

Algorithms [Intermediate Algorithms]

Satellite Data	Radiance	Reflectance	Derived Products



Products

Instrument Data	At-sensor Radiance	Land Reflectance	Designated Observables
[sensor algorithms]		Water-leaving Reflectance	
[decision algorithms]		BRDF Corrected Reflectance	
[data store/transmit alg.]]		BRDF/Topo Corr. Reflectance	

Algorithms

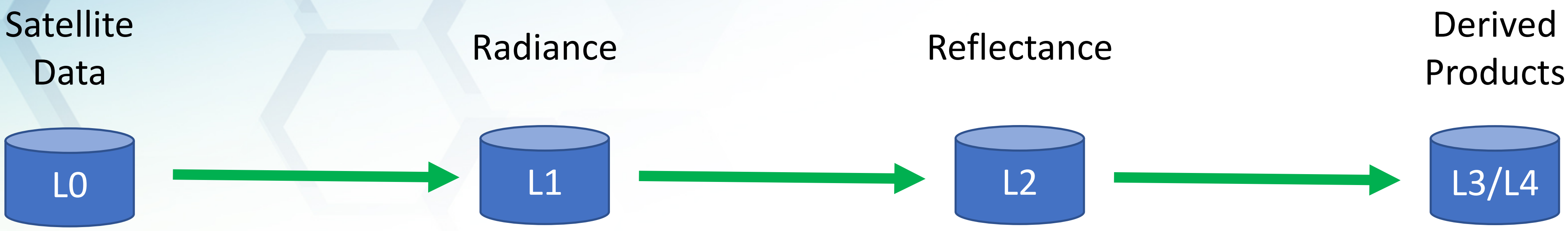
Geolocation	Atmospheric Correction*	[physically-based retrieval]
Radiance calibration	BRDF*	[empirical algorithm]
	Topographic Correction*	
	[Solar zenith/azimuth]	

* Indicates that there may likely be context-dependent variants

Framework for algorithm workflow: VSWIR TERRESTRIAL VEGETATION EXAMPLES

Products [Intermediate Products]

Algorithms [Intermediate Algorithms]



Products

Instrument Data
[sensor algorithms]
[decision algorithms]
[data store/transmit alg.]]

At-sensor Radiance

Land Reflectance
Water-leaving Reflectance
[water vapor]
[column gases in general]
[atmospheric parameters]

Designated Observables

Algorithms

Geolocation
Radiance calibration

Atmospheric Correction*
BRDF*
Topographic Correction*

[physically-based retrieval]
[empirical algorithm]

* Indicates that there may likely be context-dependent variants

Framework for algorithm workflow: VSWIR TERRESTRIAL VEGETATION EXAMPLES

Products [Intermediate Products]

Algorithms [Intermediate Algorithms]

Satellite Data	Radiance	Reflectance	Derived Products

Products

Instrument Data	At-sensor Radiance	Land Reflectance	Albedo (veg/soil), fAPAR
[sensor algorithms]		Water-leaving Reflectance	Traits (H_2O, N, LMA, Chl)
[decision algorithms]		BRDF Corrected Reflectance	Cover Fractions
[data store/transmit alg.]]		BRDF/Topo Corr. Refl.	Functional, Crop Types
			Fuel/Burn

Algorithms

Framework for algorithm workflow: VSWIR TERRESTRIAL VEGETATION EXAMPLES

Products [Intermediate Products]

Algorithms [Intermediate Algorithms]

Satellite Data	Radiance	Reflectance	Derived Products
L0	L1	L2	L3/L4

Products

Satellite Data	Radiance	Reflectance	Derived Products
Instrument Data	At-sensor Radiance	Land Reflectance	Albedo (veg/soil), fAPAR
[sensor algorithms]		Water-leaving Reflectance	Traits (H_2O, N, LMA, Chl)
[decision algorithms]		BRDF Corrected Reflectance	Cover Fractions
[data store/transmit alg.]]		BRDF/Topo Corr. Refl.	Functional, Crop Types
			Fuel/Burn

Algorithms

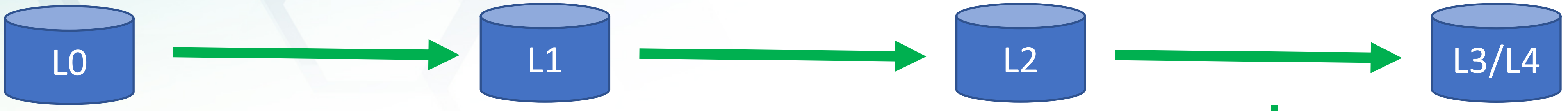
L0 → L1	L1 → L2	L2 → L3/L4
Geolocation	Atmospheric Correction*	Albedo*, fAPAR
Radiance calibration	BRDF*	Trait alg (phys/emp)
	Topographic Correction*	Classification, unmixing
		[Pre-processing]

Framework for algorithm workflow: VSWIR TERRESTRIAL VEGETATION EXAMPLES

Products [Intermediate Products]

Algorithms [Intermediate Algorithms]

Satellite Data | Radiance | Reflectance | Derived Products



Products

Instrument Data

[sensor algorithms]

[decision algorithms]

[data store/transmit alg.]]

At-sensor Radiance

Land Reflectance

Water-leaving Reflectance

BRDF Corrected Reflectance

BRDF/Topo Corr. Refl.

Albedo (veg/soil), fAPAR

Traits (H_2O, N, LMA, Chl)

Cover Fractions

Functional, Crop Types

Fuel/Burn

Algorithms

Geolocation

Radiance calibration

Atmospheric Correction*

BRDF*

Topographic Correction*

[Continuum removal]

[Vector normalization]

[DASF]

Framework for algorithm workflow: VSWIR TERRESTRIAL VEGETATION EXAMPLES

Products [Intermediate Products]

Algorithms [Intermediate Algorithms]

Satellite Data	Radiance	Reflectance	Derived Products
L0	L1	L2	L4+

Products

Instrument Data	At-sensor Radiance	Land Reflectance	[Albedo, fAPAR, Traits Cover, Types]
[sensor algorithms]		Water-leaving Reflectance	(Functional) Diversity
[decision algorithms]		BRDF Corrected Reflectance	LUE
[data store/transmit alg.]]		BRDF/Topo Corr. Refl.	Photosynthetic capacity**

Algorithms

Geolocation	Atmospheric Correction*	Main product algorithms
Radiance calibration	BRDF*	Diversity metrics
	Topographic Correction*	

** Indicates TIR dependency.

PRODUCTS shown on the slides shown thus far:

Instrument data
At-sensor radiance
Geolocated at-sensor radiance
Land Reflectance
Water-Leaving Reflectance
[Cloud/Shadow/Haze]
[Land/Water Mask]
[water vapor, column gases, etc.]
BRDF-corrected reflectance
BRDF/topo-corrected reflectance
fAPAR
Albedo (vegetation, soil)
Foliar/canopy traits (N, LMA, Chl, H_2O, lignin, etc)
Fractional cover (GV, NPV, substrate)
Land cover, vegetation, functional type,crop type
Fuel load, fuel moisture, etc.
Functional diversity

ALGORITHMS shown on the slides shown thus far:

[cloud filter]	Albedo* (soil, veg)
[pointing/prioritization]	fAPAR*
[compress/decompress]	Traits (RT approach)
[geolocation]	Traits (empirical)
Radiance calibration	Fractional cover (unmix)
[Sensor scan angles]	Veg./species classif.
[Solar zenith/azimuth]	Crop type classification
[Cloud/shadow]	Functional type classif.
[Haze]	Fuel classification
[Land/Water mask]	Live fuel moisture
Atmospheric Correction*	Burn severity
BRDF Correction*	Functional diversity
Topographic Correction*	LUE
[Vector normalization]	Photosynthetic capacity
[Continuum removal]	
[DASF]	

Framework for algorithm workflow: TIR EXAMPLES

Products [Intermediate Products]

Algorithms [Intermediate Algorithms]

Satellite Data	Radiance	LST/Emissivity	Derived Products
L0	L1	L2	L3/L4

Products

Instrument Data

At-sensor Radiance

Temperature emissivity separation

Evapotranspiration**

Water-use efficiency**

Water quality**

Volcanic eruptions**

Soil and mineral maps**

Algorithms

[sensor algorithms]

[decision algorithms]

[data store/transmit alg.]]

Geolocation

Radiance calibration

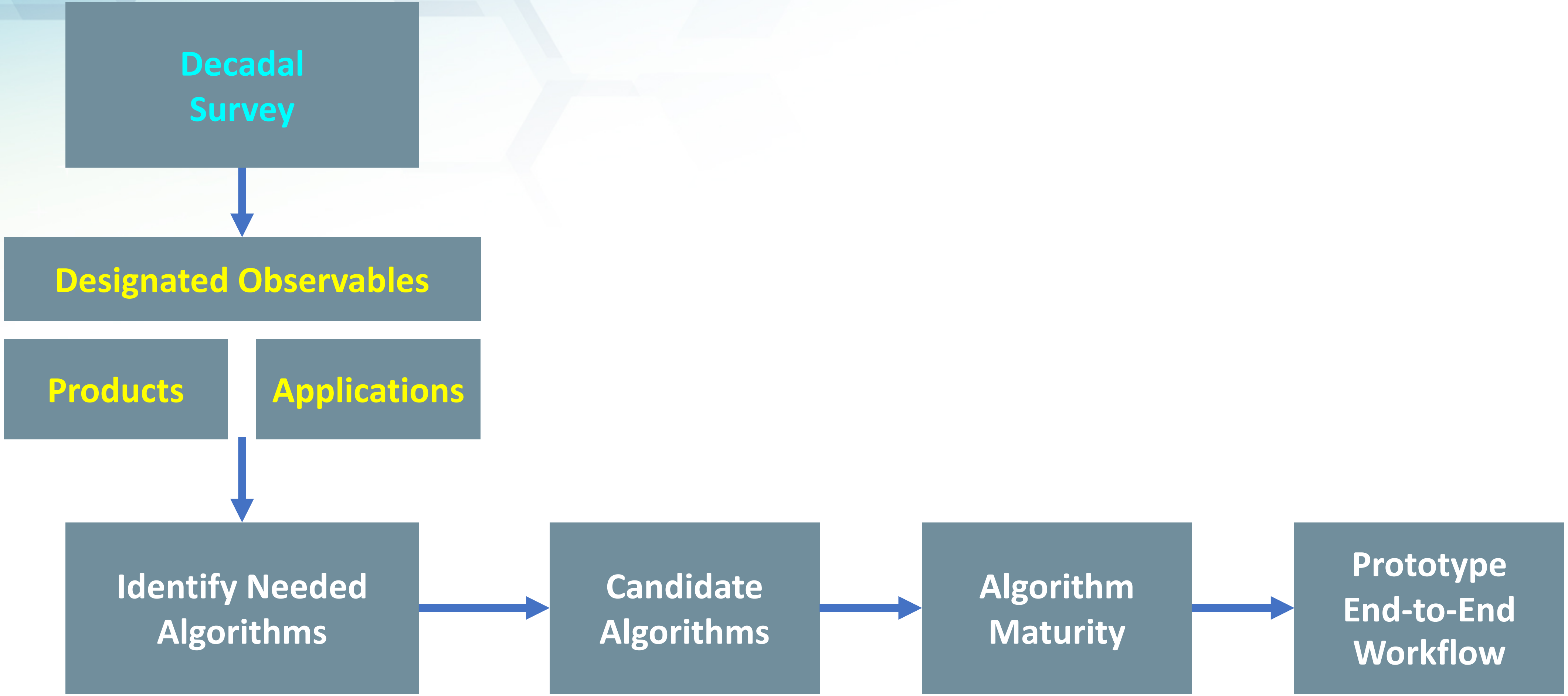
Main product algorithms

Ancillary data

Models

** Indicates VSWIR dependency.

Algorithms Team



Candidate Algorithms (example):
Atmospheric Correction of Imaging Spectroscopy Data (land)

- Business as usual – existing algorithms with airborne imagery
  - ATCOR (Richter & Schläpfer 2002) – Used by NEON
  - ATREM (Thompson et al. 2015; Gao & Goetz 1990) – Currently used by JPL (AVIRIS)
  - FLAASH (Perkins et al. 2012)
- Ongoing development
  - Optimal Estimation (OE) technique (Thompson et al. 2018)
  - Others that may be coming….

  - Wrapping in BRDF, topography, etc.

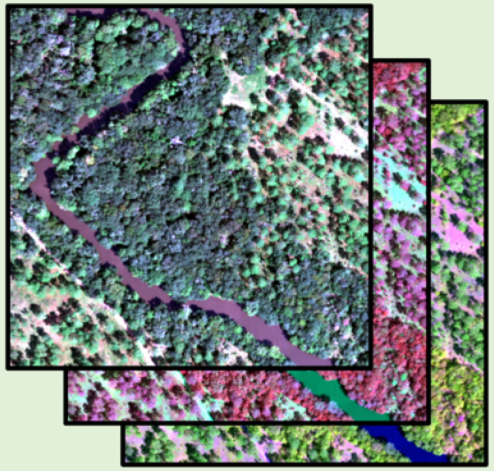
Algorithm Maturity

- Still in the process of being assessed by community
- L0/L1 algorithms tend to be ready, but depending on volume of data, SBG may require rethinking many of these
- Atmospheric Correction: business-as-usual algorithms have a long record
  - Newer methods not fully vetted or accepted
  - BRDF
- L3/L4 algorithms
  - Most are well-vetted for airborne campaigns, strong literature support
  - Few have global application
  - Data volume considerations in the trade-offs

Draft Workflow

- Vegetation traits, ET, geology

1. Image Pre-processing



L1 Reflectance

3. Image Post-processing

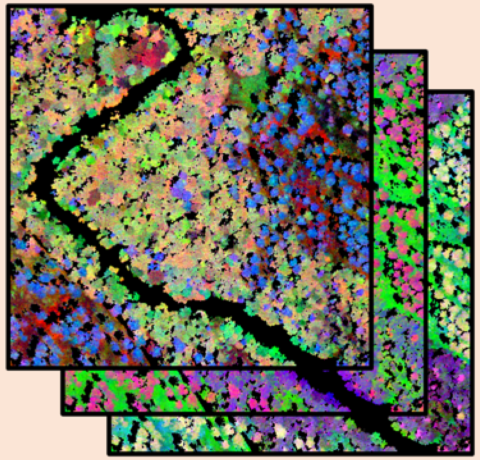
- Cloud - Shadow Mask
- Topographic Correction
- BRDF Correction
- Wavelength Resampling
- Vector Normalization
- NDVI and NIR threshold

In HyTools (Townsend Lab)

L2 Reflectance

Plot-level spectra

5. Trait mapping



- LMA
- EWT
- SLA
- Carbon
- Nitrogen
- Cellulose
- Lignin
- Water
- NSC
- Chlorophylls
- Carotenoids
- Sugars
- Starches
- Phosphorus
- Potassium
- Calcium
- Sulfur
- …

2. Field survey

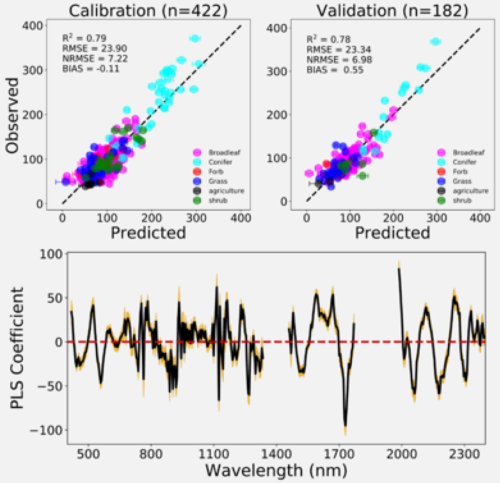
Fresh/dry leaf spectra

Leaf-level traits

Vegetation biometry

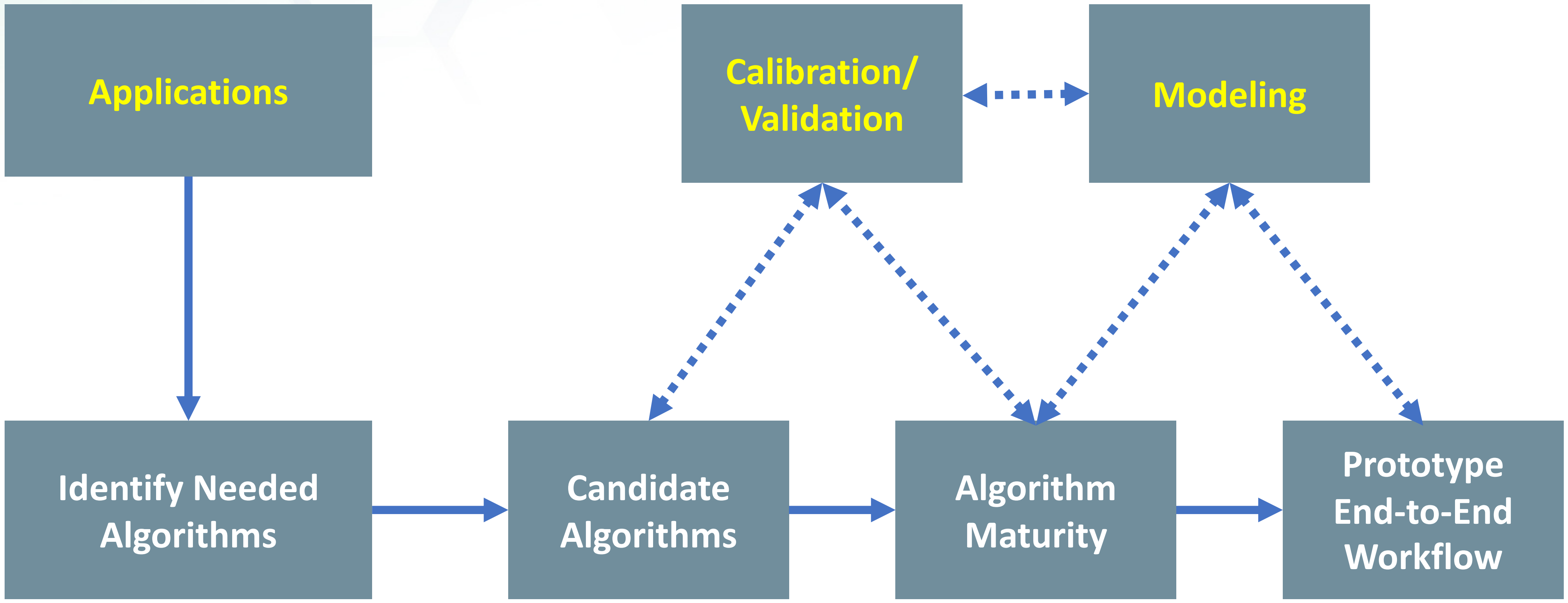
Plot-level traits

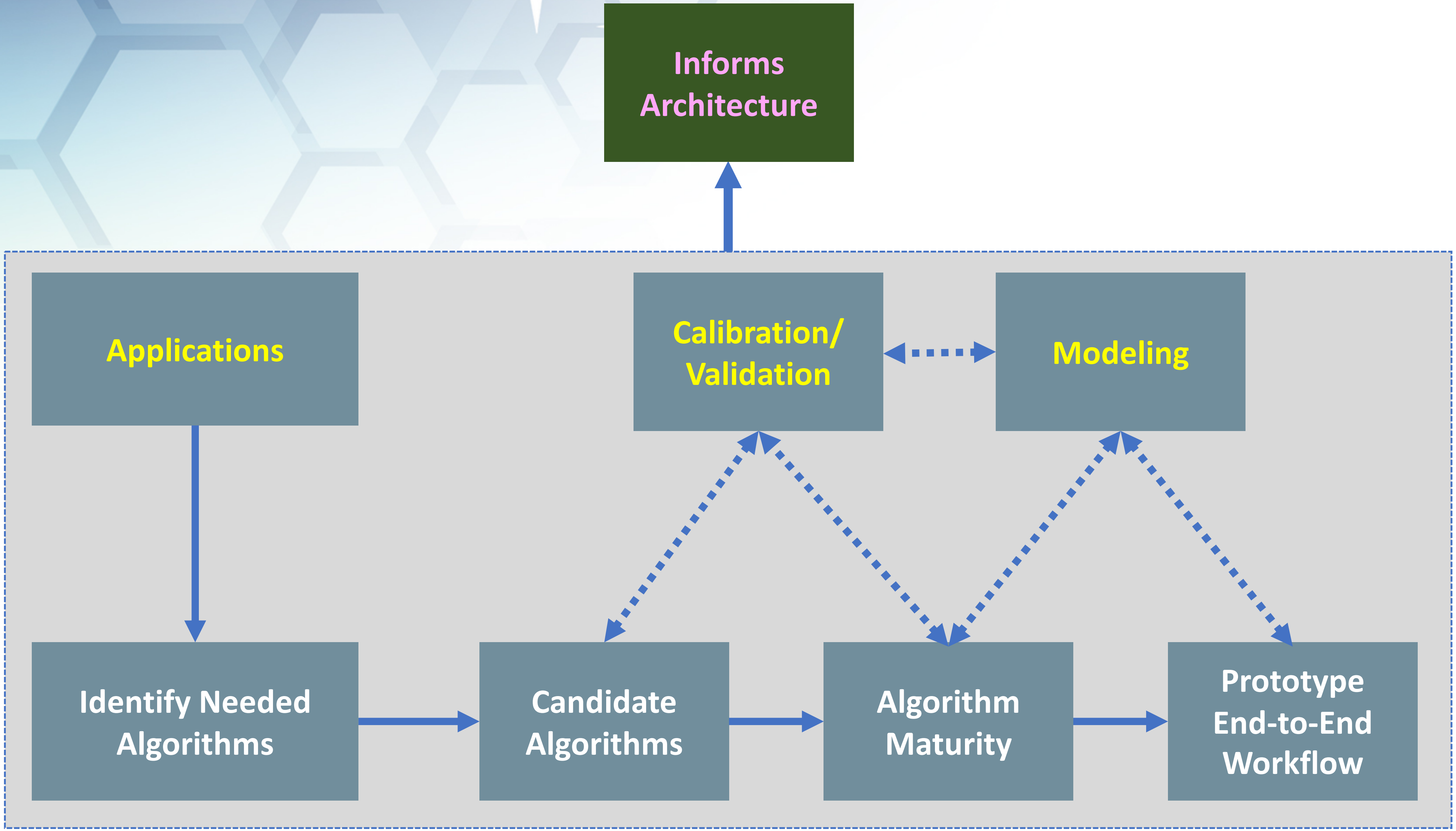
4. Trait modelling



See posters:

- Cawse-Nicholson, Townsend and Team: Full Algorithm list and traceability to ESAS 2018
- Fabian Schneider et al. – foliar traits from California HyspIRI data: 2013-2015, 2016, 2017, 2018
- Zhihui Wang et al. – foliar traits from NEON imagery across U.S.
- Wagner et al. – databases (EcoSIS/EcoSML) for cal/val, GitHub linked repositories


Applications
Calibration/ Validation
Modeling
Identify Needed Algorithms
Candidate Algorithms
Algorithm Maturity
Prototype End-to-End Workflow


Informs Architecture
Applications
Calibration/ Validation
Modeling
Identify Needed Algorithms
Candidate Algorithms
Algorithm Maturity
Prototype End-to-End Workflow

Jet Propulsion Laboratory
California Institute of Technology

jpl.nasa.gov

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